On several occasions both species of owls as well as the cats would make kills so near that the dying sounds made by the Robins could be heard distinctly, the cats being particularly unmindful of our presence in this respect, one cat killing three birds within twenty-five feet of a party of four one night within a very few minutes. The toll these raptores and cats collected from the flock was enormous.

A résumé of the study produces these evident facts:

First, that the birds of the entire country—as shown by plumage variation—flock and feed together during the winter season, but segregate into small bunches, probably family groups and units of such, of their own race, at night.

Second, that in feeding they cover a radius of at least twelve miles. Thus the birds of a single roost range and feed over a territory of somewhat more than 452 square miles, at the least estimate.

Third, that their migration during the winter is decidedly irregular and determined solely, or nearly so, by the presence of desirable food.

And Fourth, that in banding together to protect themselves from their enemies they defeat their own purpose, as do most other birds with this habit, and, instead, open themselves to the united attack of every possible enemy for miles around.

WINSLOW, ARKANSAS.

CURVATURE OF WING AND SOARING FLIGHT

BY WILLIAM BREWSTER TABER, JR.

In his paper, "The Soaring of Raptorial Birds",[1] Mr. Palmer has brought our attention to the fact that soaring is made possible by upward moving air currents. However, in his explanation of the phenomenon he considers the wing to be flat. I would like to point out that the concave curvature of the under surface of bird wings is an essential factor in soaring flight, and the effects derived therefrom. The principle involved is identical with the principle of the impulse steam or water turbine which has been utilized in a commercial way by mechanical engineers for a hundred years or more.

In order to understand the principle it will be necessary to resort to a diagram employing the devices which engineers use. In figure 6 the heavy curved line *CD* represents the cross section of a bird wing, *C* being the thick, front edge. The bird is travelling to the left, horizontal to the ground as shown by the direction of the arrow above it.

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[1] WILSON BULLETIN, March, 1931, pp. 18-24.

The letter *D* is the back edge of the wing (the tips of the secondary wing feathers).

In this whole discussion it must ever be kept in mind that the bird is entirely free from the ground, that the direction of air currents as observed from the ground does not affect the flight, but that flight is affected only by the relative direction of the air currents in relation to the wing. So as to make this more clear let us imagine that the bird is soaring in a horizontal position a mile above the earth, and that you, gentle reader, are a very minute creature, say a louse, perched on the front edge of the wing at *C*. Then the direction of the air current as observed by you would be identical with the direction of the current upon the bird wing. The fine lines in the diagram

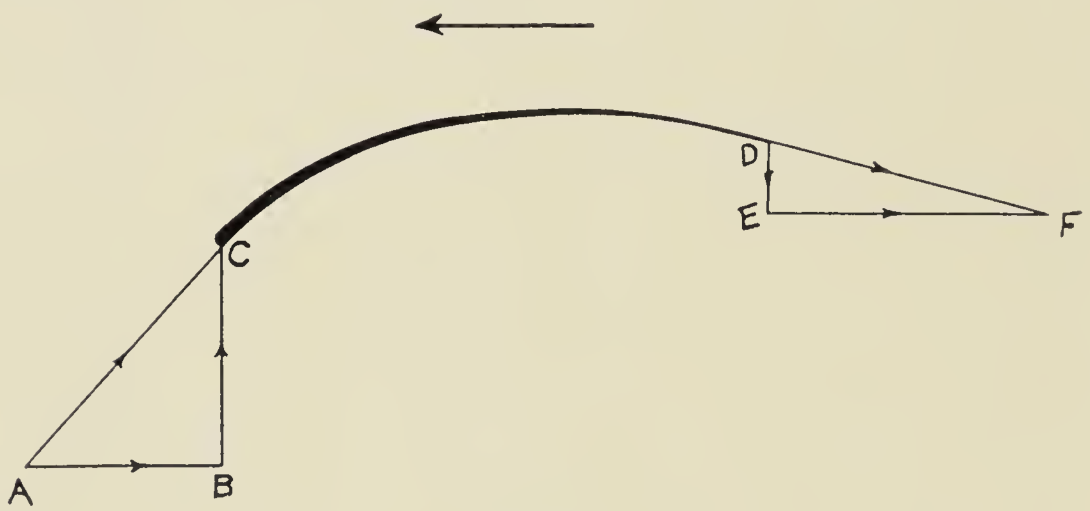

Figure 6.

such as *AC* or *EF* represent the velocities and directions of the air currents in relation to the wing. The direction of the current is shown by the arrow on the line representing that particular current, and the velocity of the current is represented by the length of the line.

Now to simplify matters let us consider our bird to be soaring to the left in an exactly horizontal direction in a current of air exactly straight up from the surface of the earth. The speed of the current upwards and its direction is represented by the line *BC*, the speed and the direction of the air rushing past the wing to the right is represented by the line *AB*. But since both air currents are acting on the wing at the same time, to you perched on the edge of the wing at *C*, there would seem to be only one current blowing and that would be in the direction of *AC* and its velocity is represented by the length of *AC*. It is easy to understand then, that so far as the effect upon the wing is concerned there is only one current acting upon it, and this is represented in direction and speed by the line *AC*. In technical language the engineer calls this line *AC* the resultant of the two components *AB* and *BC*. If you can completely grasp this idea the rest is easy.

From the diagram it is evident, that under the particular conditions illustrated, the resultant current *AC* is of such a direction that it just slips in under the edge of the wing at *C*, sweeps around under the curved surface and off at *D* in the direction *DF*. Let us now suppose an ideal condition in which there is no friction between the current and the wing. Then the current leaves the wing at *D* with exactly the same speed at which it enters at *C*. Therefore I have drawn the line *DF* exactly the same length as the line *AC*. Now what effect has the change in direction of the current had upon the wing? To discover this it is necessary to separate the line *DF* into two components, one vertical and the other horizontal, for we wish to find out if the change in direction of the current caused by the curvature of the under surface of the wing tends to overcome the force of gravity which acts vertically (hence the vertical component), and tends to thrust the bird forward in the direction in which it is soaring (hence the horizontal component). These two components of the line *DF* are *DE* and *EF*. In other words the effect of the velocity of the current acting on the wing as represented by *DF* is equivalent to the combined effects of the velocities of two distinct currents, one acting straight downward with a velocity represented by *DE*, and the other straight backward with a velocity represented by *EF*.

Now it can be seen that the total lifting effect upon the bird is due not only to the lifting effect of the rising air current as represented by *BC* but in addition there is a lifting effect caused by the change in direction of the current due to the curved under surface of the wing, and this lifting effect is proportional to the length of the velocity line *DE*. Thus the total lifting effect is proportional to *BC* plus *DE*, which is considerably greater than *BC* by itself. If the bird is to maintain its altitude and still soar in a horizontal direction, *BC* plus *DE* must be of sufficient velocity to produce a lifting effect just great enough to overcome the force of gravity. If a greater lifting effect is produced the bird will rise. If a lesser lifting effect is produced the bird will lose altitude.

Now let us discuss the horizontal motion of the bird. By comparing the lines *AB* and *EF* it is readily seen that *EF* is longer than *AB*. Since the horizontal component of the line representing the velocity of the air rushing out from the back edge of the wing, that is *EF*, is greater than the horizontal component of the line representing the velocity of the air rushing in under the front edge of the wing, there must be a thrust forward caused by this increase of velocity. The thrust forward will be therefore proportional to the difference in the length of the lines *EF* and *AB*. As in this particular ideal case there is no friction, the bird's velocity forward would be increased.

In practice, however, there is always some friction. Then too there is some loss of energy caused by eddying air currents under the front edge of the wing at *C* due to the resultant air current *AC* having such a direction that it does not exactly slip under the front edge. However it must be said that birds are able to make remarkably large adjustments of the slope of the wings in relation to the direction of flight as is so plainly shown in the admirable photograph of the Common Tern by Olin S. Pettingill, Jr.[2] Also there can be no doubt but that adjustments of the slope of the wings are automatically and continually made during soaring flight even though they may be so slight as to be unobservable by a person watching the bird. In spite of the quick and automatic adjustments that are continually being made there must nevertheless be in actual flight some losses caused by eddies and friction. Therefore *DF* can never be quite as great as *AC* and consequently the components *DE* and *EF* must be somewhat shorter than as shown. If the sum of *BC* plus the true *DE* is of sufficient magnitude to overcome the force of gravity the bird will rise, if not the bird will lose altitude. If it is only just enough to overcome the force of gravity the bird will just maintain its height. If the true *EF* is greater than *AB* the bird will increase its horizontal speed, if equal to *AB* it will just maintain its horizontal speed, if less than *AB* it will lose in horizontal speed.

There are countless adjustments and combinations of adjustments of wings, tail, position of head and legs whereby the bird may control the thrust forward and upward, which are too intricate and complex to discuss at present. However important these adjustments may be to successful soaring flight, it is certain that the essential factor is the concave curvature of the under surface of the wing, by means of which the directions of the air currents are changed, causing the necessary lift and forward thrust.

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[2]Wilson Bulletin, September, 1931, Fig. 40, page 170.